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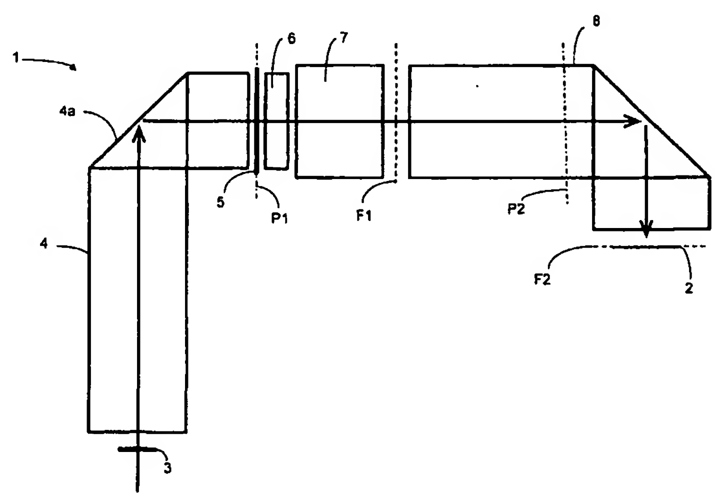
(54) Title: OPTICAL SYSTEM, IN PARTICULAR AN ILLUMINATION SYSTEM OR PROJECTION OBJECTIVE OF A MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS



(57) Abstract: The invention concerns an optical system, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus, comprising at least one polarisation-influencing optical arrangement (200, 400, 550) which has at least two polarisation-influencing optical elements (210, 220) of optically active material, wherein at least one of said polarisation-influencing elements (210, 220) is arranged rotatably.

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Optical system, in particular an illumination system or projection objective of a microlithographic projection exposure apparatus

BACKGROUND OF THE INVENTION

1. Field of the invention

The invention concerns an optical system, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus. In particular the invention concerns an illumination system or a projection objective of a microlithographic projection exposure apparatus with a polarisation-influencing optical arrangement which permits enhanced flexibility in affording a desired polarisation distribution.

2. Description of the related art

Microlithography is used for the production of microstructured components such as for example integrated circuits or LCDs. The microlithography process is carried out in what is referred to as a projection exposure apparatus having an illumination system and a projection objective. The image of a mask illuminated by means of the illumination system (= reticle) is in that case projected by means of the projection objective on to a substrate (for example a silicon wafer) which is coated with a light-sensitive layer (photoresist) and arranged in the image plane of the projection objective in order to transfer the mask structure on to the light-sensitive coating on the substrate.

Various approaches are known for specifically setting given polarisation distributions in the pupil plane and/or in the reticle in the illumination system for optimising the imaging contrast.

WO 2005/069081 A2 discloses a polarisation-influencing optical element which comprises an optically active crystal and involves a thickness profile which varies in the direction of the optical axis of the crystal.

It is known inter alia from WO 2006/077849 A1 to arrange an optical element in a pupil plane of an illumination system or in the proximity thereof, for conversion of the polarisation state, the optical element having a plurality of variable optical rotator elements by which the polarisation direction of incident, linearly polarised light can be rotated with a variably adjustable rotational angle. The variable rotational angle or polarisation state afforded by those rotator elements is in particular also adjusted in accordance with the measurement result supplied by a device for measuring the polarisation state in order to adapt for example two different systems to each other.

WO 2005/031467 A2 discloses, in a projection exposure apparatus, influencing the polarisation distribution by means of one or more polarisation manipulator devices which can also be arranged at a plurality of positions and which can be in the form of polarisation-influencing, optical elements which can be introduced into the beam path, wherein the action of those polarisation-influencing elements can be varied by altering the position, for example rotation, decentering or tilting, of the elements.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an optical system and in particular an illumination system or a projection objective of a microlithographic

projection exposure apparatus, which has enhanced flexibility in providing a desired polarisation distribution.

That object is attained by the features of independent claim 1.

An optical system according to the invention, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus, comprises at least one polarisation-influencing optical arrangement which has at least two polarisation-influencing optical elements of optically active material, wherein at least one of said polarisation-influencing elements is arranged rotatably.

The fact that, in accordance with the invention, there are provided at least two polarisation-influencing optical elements of optically active material, wherein least one of said polarisation-influencing elements is arranged rotatably, affords the possibility of variably positioning those polarisation-influencing optical elements by means of rotation as desired in the optical system and possibly providing for mutual superimposition thereof to a differing degree in the beam path, thereby affording a high level of flexibility in terms of adjustability of polarisation distributions. In that respect in particular overlap regions of the two polarisation-influencing optical elements in the beam path can be created, avoided, or specifically altered by means of simply rotating the element(s) in order to produce different overall rotational effects depending on whether incident light passes through both polarisation-influencing optical elements, only one thereof or none thereof, in dependence on the overall thickness of optically active material which is afforded by the superimpositioning of the elements.

A further advantage of the arrangement according to the invention is that (for example in comparison with a configuration having wedge members which are displaceable relative to each other), it is possible to use almost the entire pupil

area as a desired defined polarisation state or a defined polarisation distribution can be achieved substantially over the entire pupil plane.

In accordance with a preferred embodiment, each of said polarisation-influencing elements is arranged rotatably. In particular, the polarisation-influencing elements may be arranged rotatably independently of each other.

In accordance with a preferred embodiment the at least two polarisation-influencing optical elements are each of a constant thickness which once again preferably is so selected that each of those elements causes a rotation of the polarisation direction of linearly polarised light through 90° or through an odd multiple thereof. In that case, when passing through both polarisation-influencing elements, the polarisation state is consequently rotated through 180°. With that configuration variations in the respective rotational position of the polarisation-influencing elements make it possible, from initially linearly polarised light of a constant polarisation direction, to create a plurality of different polarisation distributions, in which respect individual regions of the pupil can be rotated in different ways in respect of the polarisation direction thereof either through 90° (when passing only through one of the elements) or can remain unchanged (when passing through both elements or through none of the elements).

In accordance with a preferred embodiment the polarisation-influencing optical arrangement is arranged at least in the immediate proximity of a pupil plane of the optical system.

In accordance with a preferred embodiment there is at least one neutral position for the polarisation-influencing optical arrangement in which the at least two polarisation-influencing optical elements leave the polarisation state of the light passing through the arrangement substantially unaltered. That has the advantage that the overall arrangement can remain permanently in the

optical system even if for example no change in the polarisation state is desired.

In accordance with a preferred embodiment there is at least one position for the polarisation-influencing optical arrangement in which the preferred polarisation direction of linearly polarised light impinging on the arrangement is rotated through 90°. That makes it possible in a flexible fashion to select a setting as a 90° retarder which, by virtue of the action of the polarisation-influencing optical arrangement between two portions of an optical system, is suitable for implementing compensation of the phase jumps which occur in the respective portions (for example as a consequence of reflection phenomena at mirrors). In that case two mutually perpendicular polarisation states are interchanged by the action of the polarisation-influencing optical arrangement according to the invention as a 90° retarder so that summing of the phase jumps in the second portion precisely cancels out same in the first portion.

In accordance with a preferred embodiment the at least two polarisation-influencing optical elements are arranged in such a way that the optically active surface thereof in the beam path of the optical system is of a respective geometry which is in the shape of a sector of a circle and preferably semicircular. In that case once again preferably the at least two polarisation-influencing optical elements are arranged rotatably in such a way that the optically active surfaces thereof supplement each other in at least one rotational position of the polarisation-influencing optical elements, to constitute an overall circular surface (in plan view or as a projection). As a consequence of the semicircular geometry of the respective optically active surfaces of the polarisation-influencing elements, suitable rotation of those elements makes it possible to produce regions of a geometry in the shape of a segment of a circle and with mutually different polarisation directions. Those polarisation distributions firstly include what is referred to as 'quasi-tangential' polarisation distribution (also referred to as 'X-Y-polarisation') which, in a polarisation distribution which is tangential in a first approximation, includes a light

component with a preferred polarisation direction in the X-direction and a light component with a preferred polarisation direction in the Y-direction, wherein those two light components can be in conformity in particular both in respect of their overall surface area occupied in the light beam cross-section and also in respect of their intensity (here the X-axis and the Y-axis are assumed to be mutually perpendicular axes of a Cartesian co-ordinate system, wherein the Z-axis which is perpendicular to the X-axis and the Y-axis extends parallel to the optical system axis or the light propagation direction).

The polarisation distributions which can be produced however also include polarisation distributions with magnitudes of the vertical and horizontal poles, which are varied in relation to the above-defined distribution and in respect of which therefore the light components with the preferred polarisation direction in the X-direction and with the preferred polarisation direction in the Y-direction are not in conformity in respect of their total area occupied in the light beam cross-section and in respect of their intensity respectively. In other words, the polarisation-influencing optical arrangement according to the invention can also create polarisation distributions in respect of which the relative size relationships of the areas present in the light beam cross-section, with a constant preferred polarisation direction, can be continuously varied.

In accordance with a further preferred configuration the polarisation-influencing optical arrangement has a further optical element of birefringent crystal material having an optical crystal axis oriented perpendicularly to the optical system axis. Preferably that further optical element is arranged rotatably about the optical system axis. Furthermore that further optical element preferably has a lambda/4 plate or an arrangement of lambda/4-plates. That further optical element is preferably arranged only in a central partial region of the light beam passing through the polarisation-influencing optical arrangement.

This design configuration makes it possible to produce polarisation distributions in which circularly polarised light or also effectively unpolarised light is

produced in a central region of the pupil (the size of that region depending on the extent of the further optical element).

In that respect the invention makes use of the fact that, in the arrangement according to the invention, circularly polarised light passes through the optically active material in an uninfluenced condition in respect of the polarisation state as the circularly polarised state represents an inherent state of the optically active material. Furthermore, by means of rotation of said further optical element (lambda/4-plate), it is possible to adjust the orientation of the optical crystal axis thereof relative to the polarisation direction of the light impinging on the arrangement, in other words, the lambda/4-plate can be displaced between a position in which it converts the linear entrance polarisation into circular polarisation and a position in which it leaves the linear entrance polarisation unchanged.

In accordance with a further embodiment said further optical element can also have a matrix-like or chessboard-like arrangement of lambda/4-plates. In that case the individual regions of that matrix or chessboard-like arrangement can have optical crystal axes which are rotated through 90° relative to each other so that the regions in question convert the linear entrance polarisation alternately into right-circularly and left-circularly polarised light respectively, from which once again unpolarised light is set in the central region of the pupil by superimpositioning of the components in the imaging process.

The above-described exploitation of the general principle whereby circularly polarised light passes through the optically active material without being influenced in respect of the polarisation state as the circularly polarised state represents an inherent state of the optically active material is not limited to the polarisation-influencing arrangement according to the invention but can also be implemented generally in other arrangements or optical systems.

In accordance with a further aspect the invention also concerns an illumination system of a microlithographic projection exposure apparatus, wherein different illumination settings can be set in the illumination system and wherein a polarisation distribution present in the illumination system can be adapted to the respectively set illumination setting by rotation of at least one optical element.

In that case those illumination settings can differ by the size and/or the shape of illumination poles produced, in which case the polarisation distribution can be continuously adapted to the size and/or the shape of those illumination poles.

In accordance with a preferred embodiment at least one of those illumination settings is an annular illumination setting.

In accordance with a preferred embodiment the at least one optical element is made from optically active material.

In accordance with a further aspect the invention also concerns a method of setting the polarisation distribution in at least one illumination pole, in particular in an optical system or in an illumination system having the above-described features, wherein setting of the polarisation distribution is effected by rotation of at least one optical element.

In accordance with a further aspect the invention also concerns an optical system, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus, comprising at least one optical element of optically active material, wherein said optical element is so arranged that in operation of the optical system it is irradiated at least region-wise with circularly polarised light.

In accordance with a further aspect the invention also concerns a method of operating an optical system, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus, wherein said system has at least one optical element of optically active material, wherein said optical system is irradiated at least region-wise with circularly polarised light.

The invention further concerns a microlithographic projection exposure apparatus, a method of microlithographic production of microstructured components and a microstructured component.

Further configurations of the invention are set forth in the description and the appendant claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is described in greater detail hereinafter by means of embodiments by way of example illustrated in the accompanying drawings in which:

Figure 1	is a diagrammatic view of the structure of an illumination system of a microlithographic projection exposure apparatus according to the invention;
Figure 2	is a diagrammatic side view of the structure of a polarisation-influencing optical arrangement according to the invention;
Figures 3a–3k	show diagrammatic views to illustrate the polarisation distributions which can be obtained for a predetermined entrance polarisation distribution (Figure 3a) by different

rotational positions of the polarisation-influencing optical elements of Figure 2 (Figures 3b – 3k);

Figure 4 shows a diagrammatic side view to illustrate the structure of a polarisation-influencing optical arrangement according to the invention, in a further embodiment;

Figures 5a –5d show diagrammatic views to illustrate the polarisation distributions which can be obtained for a predetermined entrance polarisation distribution (Figure 5a) by different rotational positions of the polarisation-influencing optical elements of Figure 4 (see Figures 5b – 5c), and a further alternative configuration of a polarisation-influencing optical arrangement according to the invention (Figure 5d);

Figures 6 – 7 show diagrammatic views to illustrate the structure of a polarisation-influencing optical arrangement according to the invention in a further embodiment and exit polarisation distributions which can be produced by means of such an arrangement; and

Figures 8a – 8e show diagrams to illustrate different illumination settings which can be set in an optical system.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 is a diagrammatic view showing the structure in principle of an illumination system of a microlithographic exposure apparatus in accordance with an embodiment of the invention.

The illumination system 1 serves for the illumination of a structure-bearing mask (reticle) 2 with light from a light source unit (not shown) which includes for example an ArF laser for a working wavelength of 193 nm and a beam-forming optical system generating a parallel light beam.

The parallel light beam of the light source unit, in accordance with the illustrated embodiment, firstly impinges on a diffractive optical element 3 (also referred to as the 'pupil defining element') which produces a desired intensity distribution (for example dipole or quadrupole distribution) by way of an angular radiation characteristic defined by the respective diffracting surface structure in a pupil plane P1. As shown in Figure 1 disposed downstream of the diffractive optical element 3 in the light propagation direction is an optical unit 4 which has a zoom objective producing a parallel light beam of variable diameter, and an axicon. Different illumination configurations are produced by means of the zoom objective in conjunction with the upstream-disposed diffractive optical element 3, in the pupil plane P1, depending on the respective zoom position and position of the axicon elements. The optical unit 4 further includes a direction-changing mirror 4a.

In accordance with the embodiment a polarisation-influencing optical arrangement 5 is disposed in the pupil plane P1. This arrangement can involve any of the configurations described hereinafter of a polarisation-influencing optical arrangement.

Disposed downstream of the polarisation-influencing optical arrangement 5 in the light propagation direction in the beam path is a light mixing device 6 which in per se known manner has an arrangement comprising microoptical elements suitable for producing a light mixture. The light mixing device can alternatively also involve a honeycomb condenser or a bar integrator of material which is transparent for light at the working wavelength such as for example quartz glass or also crystalline calcium fluoride.

The light mixing device 6 is followed in the light propagation direction by a lens group 7, downstream of which is a field plane F1 with a reticle masking system (REMA), the image of which is produced on the structure-bearing mask (reticle) 2 arranged in the field plane F2, by an REMA objective 8 at a downstream position in the light propagation direction, and which thereby delimits the illuminated region on the reticle 2. The structure-bearing mask 2 is imaged with a projection objective (not shown here) on to a wafer or a substrate provided with a light-sensitive layer.

Referring to Figure 2, shown therein is a merely diagrammatic side view of a polarisation-influencing optical arrangement 200. The polarisation-influencing optical arrangement 200 includes a first polarisation-influencing optical element 210 and a second polarisation-influencing optical element 220 which are arranged rotatably independently of each other about a common axis of rotation (which in the illustrated embodiment coincides with the optical system axis OA). Implementation of that rotatable arrangement can be effected for example by the optical elements 210, 220 each involving a respective extent beyond the optically used area and by being held in their respective region which is not optically used in a holding element (not shown) for example by way of a clamping mounting or an adhesive mounting which in turn is rotatable by way of a (preferably actuable) rotating device. According to a further embodiment, only one of the polarisation-influencing optical elements 210 and 220 is arranged rotatably.

The two polarisation-influencing optical elements 210 and 220 are each produced in the form of planar plates from optically active crystalline quartz, wherein the optical crystal axis of the respective crystal material is oriented in parallel relationship with the above-mentioned axis of rotation (that is to say also with the optical system axis, corresponding to the z-axis in the illustrated co-ordinate system). Furthermore the polarisation-influencing optical elements 210, 220 in the illustrated embodiment are each in the form of planar plates of constant thickness, the thickness being so selected that the elements 210, 220

produce rotation of the polarisation direction of linearly polarised light through 90° or an odd multiple thereof. When using synthetic, optically active crystalline quartz with a specific rotational capability α of about 323.1°/mm at a wavelength of 193 nm and at a temperature of 21.6°C, that condition corresponds to a thickness of the polarisation-influencing optical elements 210, 220 of 278.5 μm or an odd multiple thereof. For natural quartz, for comparative purposes, optical activity was determined for example in respect of O_a (natural quartz) = 325.2 $\pm$ 0.5°/mm (at ambient temperature between 20°C and 25°C, wherein a temperature dependency was ascertained on $\Delta O_a/\Delta T$ = 2.37 mrad/(mm°C) $\pm$ 0.14 mrad/(mm°C).

The polarisation-influencing optical elements 210 and 220, the geometry of which can basically be selected as desired (for example in the form of circular plates or rectangular plates) are so arranged in the beam path, in accordance with the illustrated embodiment, that the optically effective surface of each of those elements 210, 220, in the beam path of the optical system, is respectively of a semicircular geometry. In the diagrammatic views in Figures 3b – 3k, those respective optically effective surfaces of the elements 210, 220 are shown by hatchings which differ from each other, wherein an overlap region which is present in dependence on the respective rotational position of the individual elements 210, 220 is identified by corresponding doubled hatching. These views also show the polarisation distribution which is set by the action of the elements 210, 220 downstream of the polarisation-influencing optical arrangement 200 in the light propagation direction, more specifically by way of the direction of the arrows indicating the respective preferred polarisation direction. Accordingly those arrows are only shown here as single arrows (and not as double arrows) in order better to illustrate the actual rotational angle, in which respect however for example a rotation of the entrance polarisation through a rotational angle of 180° ultimately leaves the polarisation distribution unaltered.

In the arrangements 310 and 320 respectively shown in Figure 3b and 3c the polarisation-influencing elements 210 and 220 are so positioned that they overlie each other completely. Consequently as a result there is a semicircular region 311 and 321 respectively with a polarisation direction which is unaltered behind the polarisation-influencing optical arrangement 200 with respect to the entrance polarisation (facing in the Y-direction in Figure 3a), and an also semicircular region 312 and 322 respectively in which the polarisation direction has been rotated through 180°. Accordingly therefore both with the setting shown in Figure 3b and also with that shown in Figure 3c, in respect of the action of the polarisation-influencing optical arrangement 200, the exit polarisation distribution corresponds to the entrance polarisation distribution so that each case involves a neutral position of the arrangement 200, which does not alter the polarisation distribution.

In Figure 3d and Figure 3e the positions of the polarisation-influencing optical elements 210 and 220 are so selected that the optically effective surfaces thereof do not overlap but supplement each other to afford a circular overall surface (in plan view or as a projection). Consequently rotation of the polarisation direction through 90° takes place in each two respective semicircular regions 331 and 332, and 341 and 342 respectively. Such a setting is particularly suitable when the action of the polarisation-influencing optical arrangement, between two portions of an optical system, is intended to implement compensation of the phase jumps occurring in the respective portions of the optical system, for example as a consequence of reflection phenomena at mirrors. In this case, two mutually perpendicular polarisation states are interchanged by the action of the polarisation-influencing optical arrangement according to the invention as a 90° retarder so that summing of the phase jumps in the second portion precisely cancels out that in the first portion. That principle of reducing/compensating for an unwanted change in the polarisation state is known for example from WO 03/077011 A1 and can thus also be implemented with the polarisation-influencing optical arrangement according to the invention.

The arrangement 360 shown in Figure 3g of the polarisation-influencing optical elements 210 and 220 is so selected that they do not overlap in two regions 362 and 364 which are in mutually opposite relationship in the Y-direction (that is to say vertically) (so that there in each case rotation of the polarisation direction through 90° takes place). In contrast the two elements 210 and 220 overlap in a region 363 so that there the polarisation direction is rotated through 180°. In the region 361 in opposite relationship to the region 363 in the X-direction none of the elements 210 and 220 respectively is in the beam path so that no rotation of the polarisation direction takes place there at all. The polarisation distribution obtained as the outcome is referred to as 'quasi-tangential' or 'X-Y-polarisation' as so to speak in a first approximation it includes tangential polarisation distribution with a light component with a preferred polarisation direction in the X-direction and a light component with a preferred polarisation direction in the Y-direction. In the case of the arrangement 360 of Figure 3g those two light components are in conformity both in respect of their total surface occupied in the light beam cross-section and also in respect of their intensity.

The arrangements shown in Figure 3f and 3h are each so selected that the overlap region of the elements 210, 220 and the region which is covered by none of the elements 210 or 220 respectively are respectively smaller (Figure 3f, regions 351, 353) or larger (see Figure 3h, regions 371, 373) than the regions respectively covered only by one of the elements 210, 220 (that is to say in Figure 3f the regions 352 and 354 and in Figure 3h the regions 372 and 374). Consequently the light components with a preferred polarisation direction in the X-direction and with a preferred polarisation direction in the Y-direction are not in conformity in respect of their total area occupied in the light beam cross-section and their intensity respectively. Varying the magnitude of the overlap region 353 and 373 respectively makes it possible to continuously vary the size of the individual poles or the areas present in the light beam cross-section, with a constant preferred polarisation direction.

In the arrangement 390 shown in Figure 3j of the elements 210 and 220, the non-overlapping regions of the elements 210 and 220 are disposed horizontally in opposite relationship in the X-direction, whereas in the vertically oppositely disposed regions 392 and 394 the elements 210 and 220 either overlap (region 394) or are not present at all (region 392). As a result the arrangement 390 of Figure 3j produces what is referred to as a 'quasi-radial' polarisation distribution in which the preferred polarisation direction, on the X-axis and the Y-axis respectively, is oriented in parallel relationship with the radius directed towards the optical system axis OA. Similarly to the above-described embodiments of Figures 3f and 3h, the embodiments of Figures 3i and 3k are modified in relation to the above-described arrangement 390 of Figure 3j in such a way that the pole size or the area of the surfaces which are present in the light beam cross-section and which are in opposite relationship in the X-direction and in the Y-direction respectively is varied with a constant preferred polarisation direction.

Hereinafter reference is now made to Figures 6 and 7 to describe a further embodiment of a polarisation-influencing optical arrangement according to the present invention. This arrangement differs from the polarisation-influencing arrangement 200 described with reference to Figures 2 and 3 in that a total of six polarisation-influencing elements are arranged in succession along the optical system axis OA and are arranged to be rotatable about the optical system axis OA (forming a common axis of rotation). Each of those elements (again made from optically active, crystalline quartz with an optical crystal axis parallel to the optical system axis OA) once again is of a constant thickness and, unlike Figures 2 and 3, is not in the shape of a semicircle but a quarter of a circle. The corresponding arrangement is shown as a plan view for example in Figure 7a (as well as Figure 7c, Figure 7e, and so forth), in which respect the digits '1', '1+2', '2+3' and so forth identify the respective element present in the circular sector in question or the elements which overlap there. As is already the case in the example of Figures 2 and 3, rotation of the individual elements

takes place about the centre point of the associated full circle. The thickness of the individual polarisation-influencing elements is so selected that the two elements which are first in the light propagation direction respectively produce a rotation of the polarisation direction of linearly polarised light through 45° or an odd multiple thereof. The next two elements which follow in the light propagation direction (that is to say the third and fourth elements of the arrangement) are of such a thickness that they produce a rotation of the polarisation direction of linearly polarised light through 90°. The two elements which further follow in the light propagation direction (that is to say the fifth and sixth elements of the arrangement) respectively cause a rotation of the polarisation direction of linearly polarised light through 135°.

As was already described by means of the example of Figures 2 and 3, the polarisation state when passing through a plurality of plates is rotated by the sum of the individual rotations of the plates through which the light respectively passes.

That arrangement achieves a further increase in flexibility in terms of providing a desired polarisation state, as described hereinafter. Figure 6 firstly shows an overview of the resulting overall rotations which can be achieved with a combination of two respective superposed elements. In that case the individual polarisation-influencing elements are consecutively numbered from '1' to '6' and the rotational angle resulting when light passes through those two plates is specified in degrees and also in the form of an arrow symbol.

Figures 7a – 7p now show, for these embodiments of the polarisation-influencing optical arrangement, a total of eight different configurations of the six polarisation-influencing optical elements together with the respectively produced exit polarisation distribution. In that respect Figure 7b shows the exit polarisation distribution related to the configuration of Figure 7a, Figure 7d shows the exit polarisation distribution associated with the configuration of Figure 7c, and so forth. In all cases the respective entrance polarisation

distribution corresponds to that of Figure 3a and Figure 5a respectively, that is to say a linear polarisation distribution with a preferred polarisation direction in the Y-direction.

The configurations of Figure 7a and Figure 7c respectively are suitable for producing a quasi-tangential polarisation distribution (Figures 7a, b) and a quasi-radial polarisation distribution (Figures 7c, d respectively), which is still better approximated to the ideal tangential and radial polarisation distribution respectively, in comparison with Figures 3g and 3j respectively.

The configuration of Figures 7e – 7f corresponds to a neutral position which as a result does not influence the polarisation state. The configuration of Figures 7g – 7h corresponds to a regular rotation of the preferred polarisation direction through 90° and thus similarly to the above-described configurations of Figure 3d and Figure 3e is suitable for minimising a remaining degree of residual polarisation in unpolarised operation.

The configuration of Figures 7i – 7j, similarly to the embodiment of Figure 3g, corresponds to the production of a quasi-tangential X-Y-polarisation which, in accordance with the further possible configuration of Figures 7k – 7l, can also be produced rotated through 45° about the optical system axis OA.

The configurations of Figures 7m – 7n and Figures 7o – 7p respectively accordingly correspond to a uniform rotation of the preferred polarisation direction through 45° (Figures 7m – 7n) and through 135° (Figures 7o – 7p) respectively.

Hereinafter, with reference to Figure 4 and Figures 5a – 5c, a polarisation-influencing optical arrangement in accordance with a further embodiment of the present invention will be described. This polarisation-influencing optical arrangement 400 firstly has the two polarisation-influencing optical elements 210 and 220 of the arrangement 200 of Figure 2 and Figure 3. In addition and

arranged upstream of that arrangement 200 in the light propagation direction (along the z-axis in the illustrated co-ordinate system), as a component part of the arrangement 400 however, there is a further optical element 410 of birefringent crystal material in which the optical crystal axis is oriented perpendicularly to the optical system axis OA, in contrast to the elements 210 and 220. In accordance with the illustrated embodiment that further optical element 410 is in the form of a lambda/4-plate and is also arranged rotatably about the common axis of rotation of the elements 210 and 220 (which in the illustrated embodiment is again coincident with the optical system axis OA) and independently of the elements 210 and 220. In addition the element 410 involves a circular geometry and in the illustrated embodiment is of a diameter which is approximately 50% of the diameter of the light beam passing through the arrangement (that is to say for example about 50% of the maximum pupil diameter).

As shown in Figures 5a – 5c, in accordance with the arrangement 400 of Figure 4, it is possible to produce from the original linear entrance polarisation distribution with a constant polarisation direction (see Figure 5a), exit polarisation distributions which by virtue of the action of the lambda/4-plate in a central region of the pupil (the size of which depends on the extent of the optical element 410) produce circularly polarised light. In that respect the effect which comes in useful is that the circularly polarised light produced by the lambda/4-plate passes through the subsequent elements 210, 220 without influencing the polarisation state as the circularly polarised state represents an inherent state of the optically active material. As the aforesaid action of producing circularly polarised light from the linear entrance polarisation distribution presupposes that the optical crystal axis in the element 410 is at an angle of substantially 45° relative to the preferred polarisation direction in the linear entrance polarisation distribution, the above-mentioned effect of producing circular polarisation can also be modified or suppressed by means of rotation of the element 410 about the optical system axis OA. In particular in the illustrated embodiment the optical element 410 does not have any

polarisation-influencing action if the optical crystal axis in the element 410 is parallel to the preferred polarisation direction of the linear entrance polarisation (that is to say in the illustrated co-ordinate system in the y-direction) as that polarisation direction again forms an inherent state in relation to the birefringent material of the lambda/4-plate.

In that sense the configuration shown in Figure 5b in which the rotational position of the plates and also the exit polarisation distribution are illustrated similarly to the view in Figure 3 corresponds to the production of a quasi-tangential polarisation distribution similarly to Figure 3g, but with a circular polarisation distribution in a central region 515 of the pupil. The arrangement 520 shown in Figure 5c, similarly to Figures 3f, corresponds to the production of an also quasi-tangential polarisation distribution with a differing size in respect of the horizontal poles 521, 523 in comparison with the vertical poles 522, 524, and with a circular polarisation distribution in a central region 525 of the pupil. Similarly, for all of the configurations already described with reference to Figures 2 and 3, by means of the polarisation-influencing optical arrangement 400 of Figure 4, it is possible to produce corresponding exit polarisation distributions involving circular polarisation in the central region of the pupil, that is to say said production of circular polarisation in the central region of the pupil is effected independently of the position of the other polarisation-influencing elements or rotator plates.

It will be appreciated moreover that the principle of a lambda/4-plate arranged upstream of the polarisation rotators or polarisation-influencing elements in the direction of propagation of the light can also be applied to the arrangement described with reference to Figures 6 and 7 in order to produce the exit polarisation distributions shown in detail in Figures 7a – 7p in each case similarly with a circular polarisation distribution in the central region of the pupil.

In accordance with a further embodiment the further optical element 410, as shown in the diagrammatic view of Figure 5d, in place of a lambda/4-plate, may

also have a matrix-like or chessboard-like arrangement 570 of lambda/4-plates, in which case mutually adjacently arranged lambda/4-plates of that matrix-like arrangement respectively have optical crystal axes which are rotated through 90° relative to each other, wherein moreover similarly to Figure 4 the arrangement is positioned for example upstream of the polarisation-influencing arrangement 200 (identified by 560 in Figure 5d) in the light propagation direction and is preferably also arranged rotatably about the optical system axis OA extending in the Z-direction. In accordance with a further alternative embodiment the further optical element 410 may also involve a matrix-like or chessboard-like distribution of polarisation-influencing elements, in which case respective adjacent elements in that distribution alternately produce a lambda/4- and a (3* lambda/4)-retardation.

Preferably in the above-described matrix-like arrangements the 'inversely' birefringent regions are arranged in point symmetry around the pupil centre. As a consequence of the superimpositioning of the individual components in the imaging process both configurations respectively permit the production of quasi-unpolarised light in the central region of the pupil. In these configurations also, the above-described action of the matrix-form arrangement can be respectively 'switched on and off' by means of rotation about 45°, through the optical system axis forming the axis of rotation. That configuration with a matrix-like or chessboard-like arrangement of lambda/4-plates (or (3* lambda/4)-plates) can also be combined with each of the polarisation-influencing arrangements described hereinbefore (with reference to Figures 2, 3 and Figures 6, 7 respectively).

Figures 8a – e show typical illumination settings which can be set in an optical system, for example an illumination system as shown in Figure 1 and which for example are preferred in accordance with the respective mask used, wherein Figure 8a shows a so-called illumination setting with 'small sigma' (also referred to as small sigma setting), Figures 8b shows an annular illumination setting, Figure 8c shows a quadrupole illumination setting also referred to as C-quad

setting and Figures 8d shows an illumination setting also referred to as quasar setting, in which the four poles of the quadrupole are arranged rotated relative to the C-quad setting through 45° in each case in relation to the x-axis and the y-axis respectively about the z-axis. Figure 8e shows an illumination setting similar to Figures 8c, but with an altered size of the poles disposed in opposite relationship in the x-direction ('horizontal' poles). A polarisation-influencing optical arrangement according to the invention can be used in particular in order to adapt the polarisation distribution which is respectively set or present in the illumination system, in terms of the pole size, continuously to the respectively set illumination setting, that is to say to the size and/or shape of the illumination poles, by rotating at least one of the polarisation-influencing optical elements.

If the invention has been described hereinafter with reference to specific embodiments, numerous variations and alternative configurations will be apparent to the man skilled in the art, for example by combination and/or interchange of features of individual embodiments. Accordingly it will be apparent to the man skilled in the art that such variations and alternative configurations are also embraced by the present invention and the scope of the invention is restricted only in accordance with the accompanying claims and equivalents thereof.

Claims

1. An optical system, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus, comprising:
   - at least one polarisation-influencing optical arrangement (200, 400, 550) which has at least two polarisation-influencing optical elements (210, 220) of optically active material,
   - wherein at least one of said polarisation-influencing elements (210, 220) is arranged rotatably.

2. An optical system according to claim 1, characterised in that each of said polarisation-influencing elements (210, 220) is arranged rotatably.

3. An optical system according to claim 1 or 2, characterised in that at least one polarisation-influencing optical element (210, 220) is rotatable in a plane perpendicular to the optical system axis (OA).

4. An optical system according to claim 2, characterised in that each of said polarisation-influencing optical elements (210, 220) is respectively rotatable in a plane perpendicular to the optical system axis (OA).

5. An optical system according to anyone of the claims 2 to 4, characterised in that said polarisation-influencing optical elements (210, 220) are arranged rotatably about a common axis of rotation.

6. An optical system according to claim 5, characterised in that the optical system has an optical system axis (OA) which is coincident with the common axis of rotation.

7. An optical system according to anyone of the preceding claims, characterised in that the at least two polarisation-influencing optical elements (210, 220) are respectively of a constant thickness.

8. An optical system according to anyone of the preceding claims, characterised in that the thickness of at least one of the at least two polarisation-influencing optical elements (210, 220) and preferably of each of those elements is so selected that it produces a rotation of the polarisation direction of linearly polarised light through 90° or an odd multiple thereof.

9. An optical system according to anyone of the preceding claims, characterised in that the optical system has an optical system axis (OA), wherein the at least two polarisation-influencing optical elements (210, 220) are arranged in direct succession along said optical system axis (OA).

10. An optical system according to anyone of the preceding claims, characterised in that the optical system has an optical system axis (OA), wherein the optically active material is respectively an optically active crystal material and the optical crystal axis is respectively parallel to the optical system axis (OA).

11. An optical system according to anyone of the preceding claims, characterised in that the optically active material is quartz, TeO_2 or $AgGaS_2$.

12. An optical system according to anyone of the preceding claims, characterised in that there is at least one neutral position of the polarisation-influencing optical arrangement, in which the at least two polarisation-influencing optical elements (210, 220) leave the polarisation state of the light passing through the arrangement substantially unaltered.

13. An optical system according to anyone of the preceding claims, characterised in that there is at least one position of the polarisation-influencing optical arrangement in which the preferred polarisation direction of linearly polarised light impinging on the arrangement is rotated through 90°.

14. An optical system according to anyone of the preceding claims, characterised in that an overlap region is variable by rotation of the at least one polarisation-influencing optical element (210, 220), wherein said overlap region is defined by light beams of light which passes through the optical system passing through both polarisation-influencing optical elements (210, 220) within the overlap region.

15. An optical system according to anyone of the preceding claims, characterised in that the at least two polarisation-influencing optical elements (210, 220) are arranged in such a way that their optically effective surface in the beam path of the optical system is respectively of a geometry in the form of a sector of a circle, preferably a semicircular geometry or a geometry in the form of a quarter of a circle.

16. An optical system according to anyone of the preceding claims, characterised in that the polarisation-influencing optical arrangement has more than two, preferably six, such polarisation-influencing optical elements.

17. An optical system according to claim 16, characterised in that at least two of said polarisation-influencing optical elements are of a mutually different thickness.

18. An optical system according to anyone of the preceding claims, characterised the optically effective surfaces of the at least two

polarisation-influencing optical elements (210, 220) completely overlap in the light propagation direction in at least one rotational position.

19. An optical system according to anyone of the preceding claims, characterised in that the optically effective surfaces of the polarisation-influencing optical elements (210, 220) in at least one rotational position supplement each other to afford a circular overall area.

20. An optical system according to anyone of the preceding claims, characterised in that the polarisation-influencing optical arrangement in at least one position of the at least two polarisation-influencing optical elements (210, 220) converts an entrance polarisation distribution with a constant polarisation direction into an approximately tangential polarisation distribution.

21. An optical system according to anyone of the preceding claims, characterised in that the polarisation-influencing optical arrangement is arranged at least in the immediate proximity of a pupil plane (P1) of the optical system.

22. An optical system according to anyone of the preceding claims, characterised in that the optical system has an optical system axis (OA) wherein the polarisation-influencing optical arrangement (400) has a further optical element (410) of birefringent crystal material having an optical crystal axis which is oriented perpendicularly to the optical system axis (OA).

23. An optical system according to claim 22, characterised in that said further optical element (410) is arranged rotatably about the optical system axis (OA).

24. An optical system according to claim 22 or claim 23, characterised in that said further optical element (410) has a lamda/4-plate or an arrangement of lamda/4-plates.

25. An optical system according to anyone of claims 22 to 24, wherein said further optical element has a matrix-like arrangement (570) of lamda/4-plates, wherein the optical crystal axes in at least two adjacent lamda/4-plates of said arrangement are rotated through 90° relative to each other.

26. An optical system according to anyone of claims 22 to 25, characterised in that said further optical element is arranged only in a central partial region of the light beam passing through the polarisation-influencing optical arrangement.

27. An optical system according to anyone of claims 22 to 26, characterised in that said further optical element involves a circular geometry.

28. An optical system according to anyone of claims 22 to 27, characterised in that said further optical element is of a diameter which is in the range of 40% to 60% of the diameter of the light beam passing therethrough in operation of the optical system.

29. An illumination system of a microlithographic projection exposure apparatus
    - wherein different illumination settings can be set in the illumination system; and
    - wherein a polarisation distribution present in the illumination system can be adapted to the respectively set illumination setting by rotation of at least one optical element.

30. An illumination system according to claim 29, characterised in that said illumination settings differ by the size and/or the shape of illumination

poles produced, wherein the polarisation distribution can be continuously adapted to the size and/or the shape of said illumination poles.

31. An illumination system according to claim 29 or claim 30, characterised in that at least one of said illumination settings is an annular illumination setting.

32. An illumination system according to anyone of claims 29 to 31, characterised in that the at least one optical element is made from optically active material.

33. An illumination system according to anyone of claims 29 to 32, characterised in that the illumination system is an optical system according to one of claims 1 to 28.

34. A method of setting the polarisation distribution in at least one illumination pole, in particular in an optical system according to anyone of claims 1 to 28 or in an illumination system according to anyone of claims 29 to 33, wherein setting of the polarisation distribution is effected by rotation of at least one optical element.

35. A method according to claim 34, characterised in that the at least one optical element is made from optically active material.

36. A method according to claim 34 or claim 35, characterised in that the at least one illumination pole is an illumination pole of an annular illumination setting.

37. An optical system, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus, comprising

- at least one optical element of optically active material;

- wherein said optical element is so arranged that in operation of the optical system it is irradiated at least region-wise with circularly polarised light.

38. A method of operating an optical system, in particular an illumination system or a projection objective of a microlithographic projection exposure apparatus, wherein said system has at least one optical element of optically active material, wherein said optical system is irradiated at least region-wise with circularly polarised light.

39. A polarisation-influencing optical system, in particular for use in an optical system according to anyone of claims 1 to 28 or an illumination system according to anyone of claims 29 to 33, wherein the arrangement has at least two polarisation-influencing optical elements (210, 220) of optically active material and wherein at least one of said polarisation-influencing optical elements (210, 220) is arranged rotatably.

40. A polarisation-influencing optical system according to claim 39, wherein each of said polarisation-influencing optical elements (210, 220) is arranged rotatably.

41. A microlithographic projection exposure apparatus having an illumination system and a projection objective, wherein the illumination system and/or the projection objective are an optical system according to anyone of claims 1 to 28 or wherein the illumination system is designed in accordance with anyone of claims 29 to 33.

42. A method of microlithographic production of microstructured components comprising the following steps:
    - providing a substrate to which a layer of a light-sensitive material is at least partially applied;

- providing a mask (2) having structures, the image of which is to be produced;
- providing a microlithographic projection exposure apparatus according to claim 41; and
- projecting at least a part of the mask (2) on to a region of the layer by means of the projection exposure apparatus.

43. A microstructured component produced in accordance with a method as set forth in claim 42.

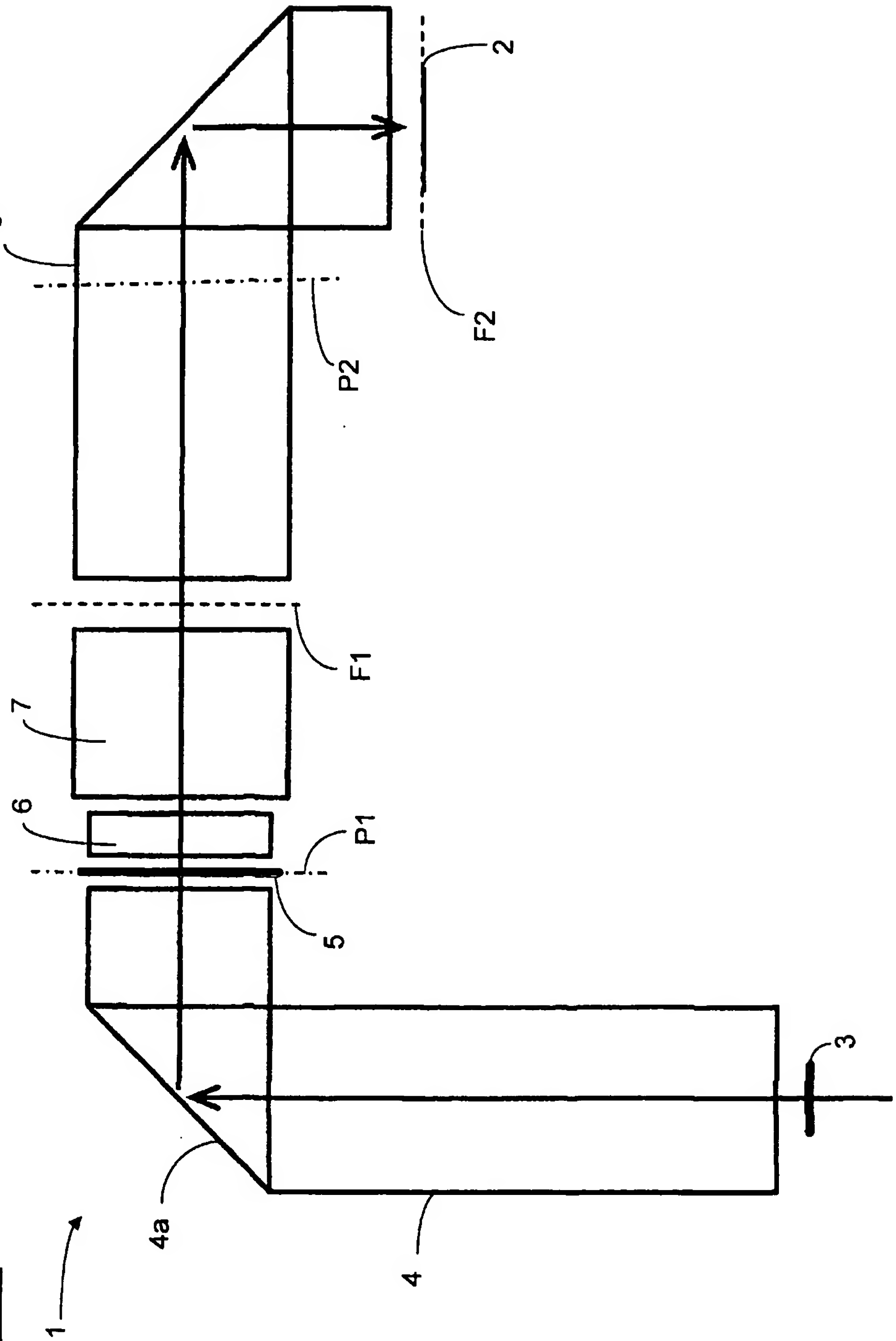


Fig. 1

Fig. 2

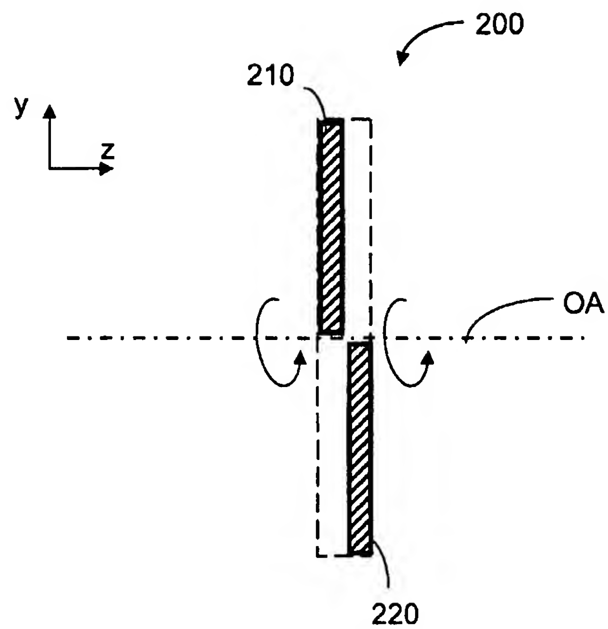


Fig. 3a

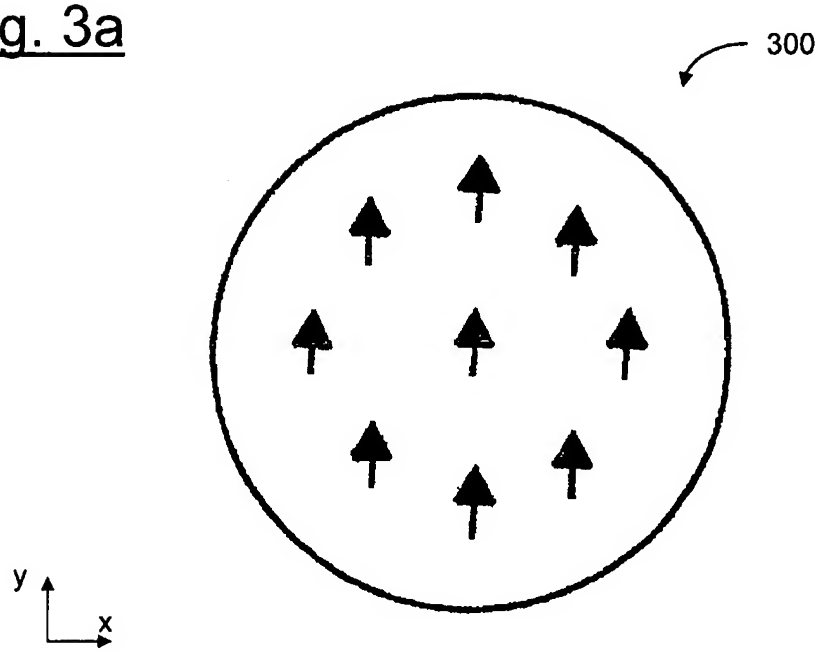


Fig. 3b

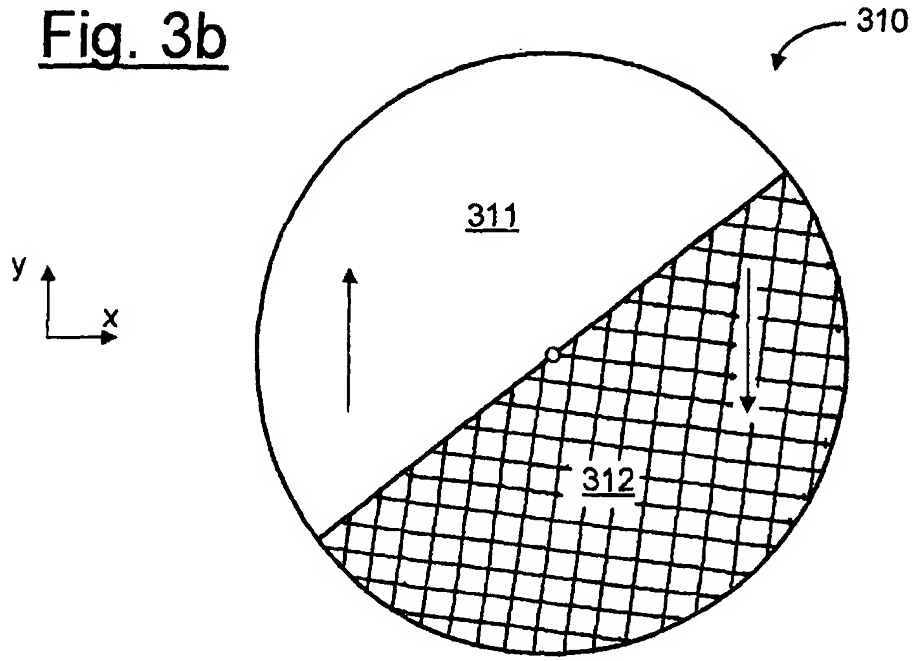


Fig. 3c

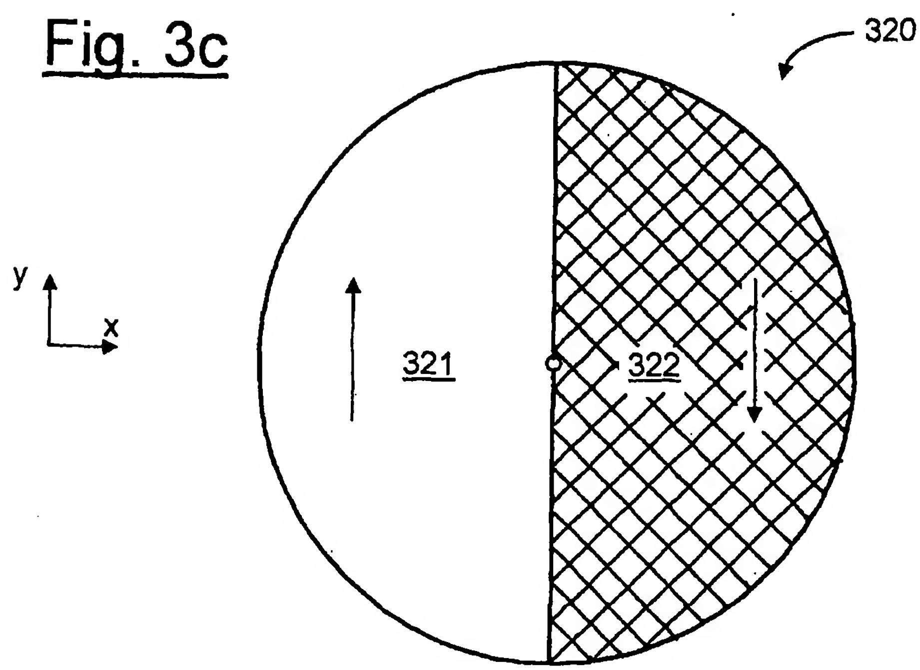


Fig. 3d

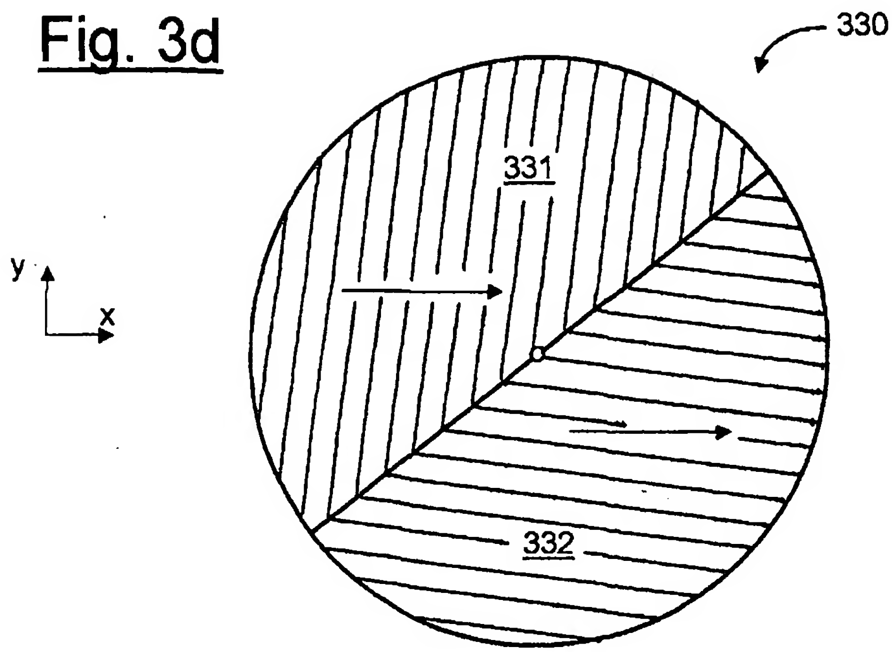


Fig. 3e

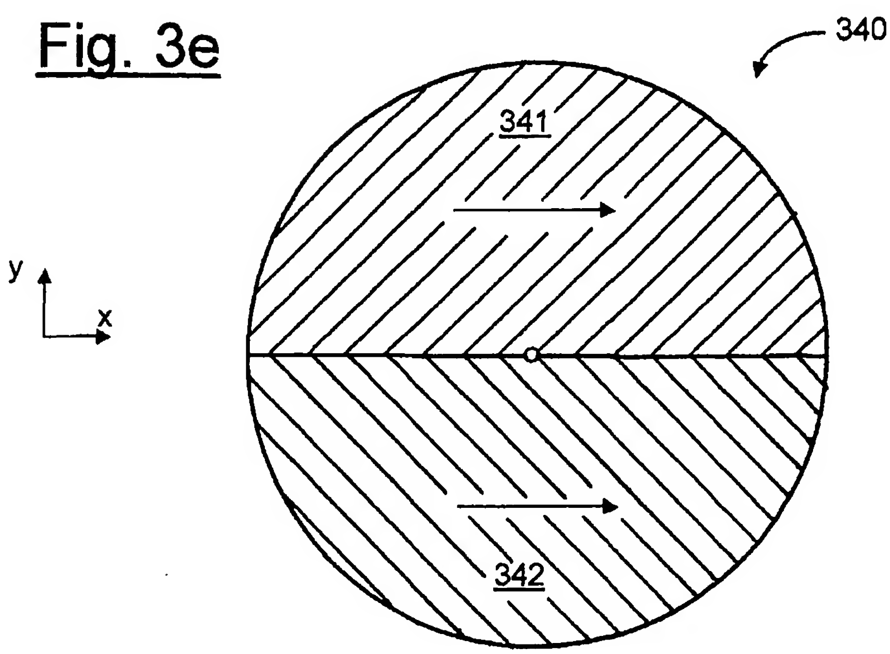


Fig. 3f

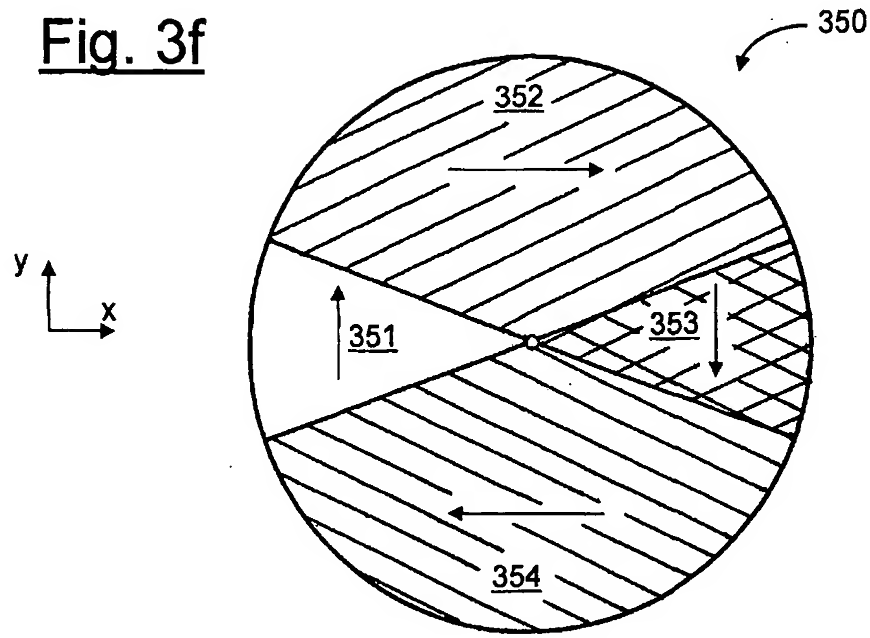


Fig. 3g

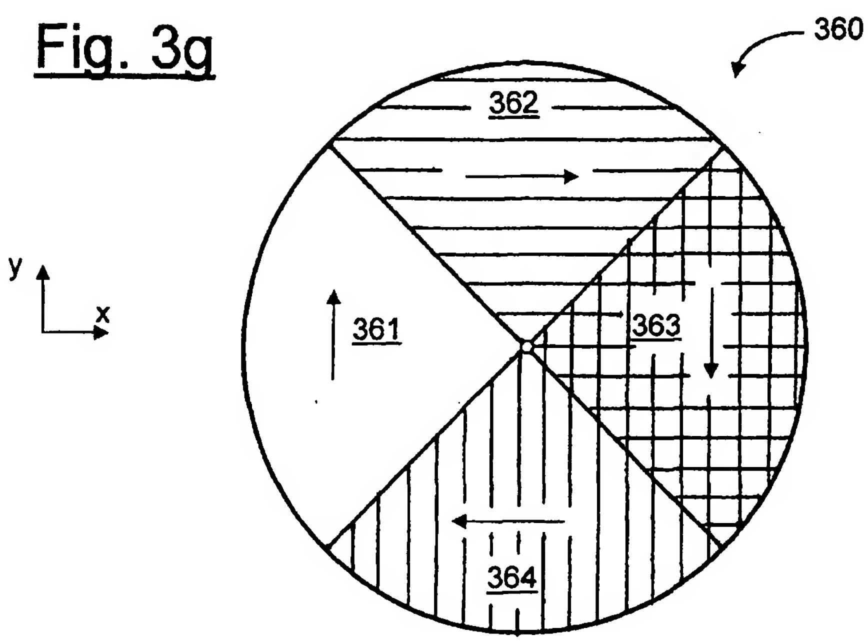


Fig. 3h

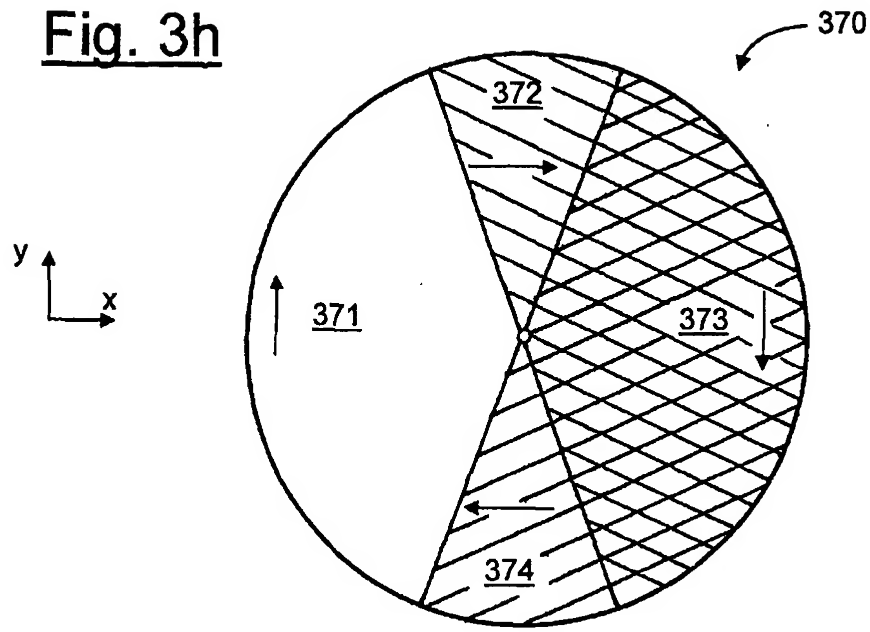


Fig. 3i

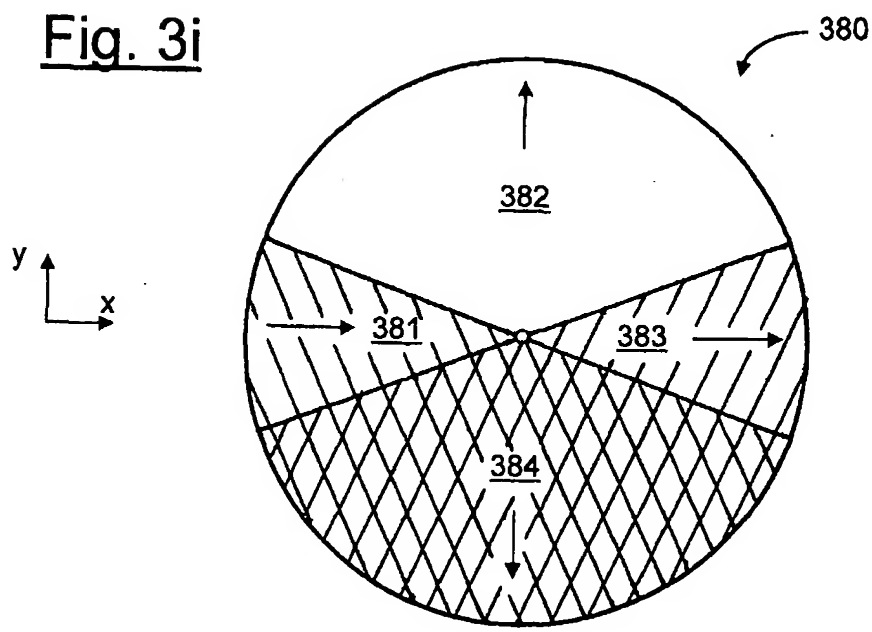


Fig. 3j

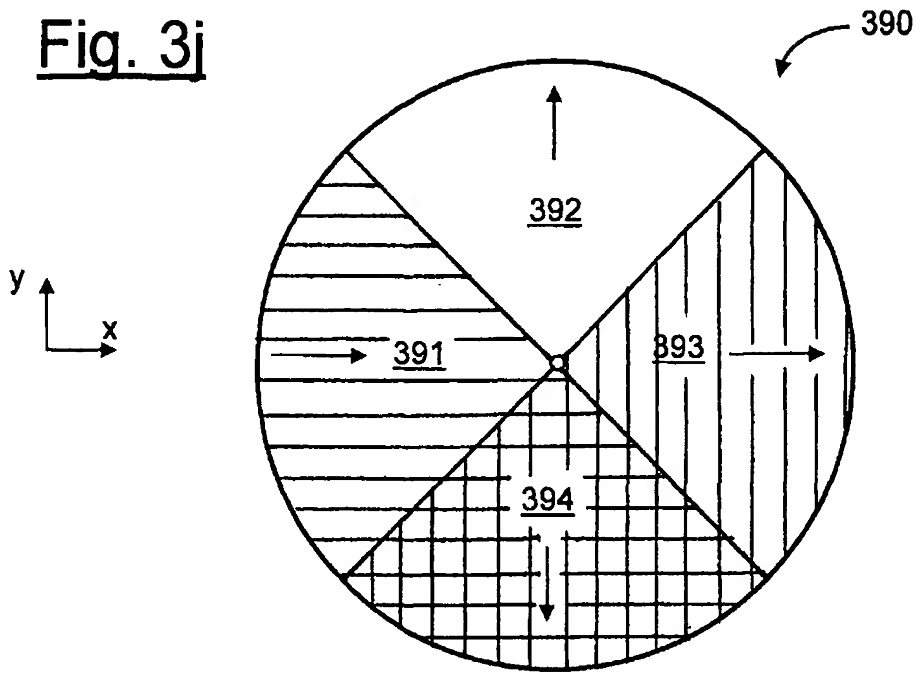


Fig. 3k

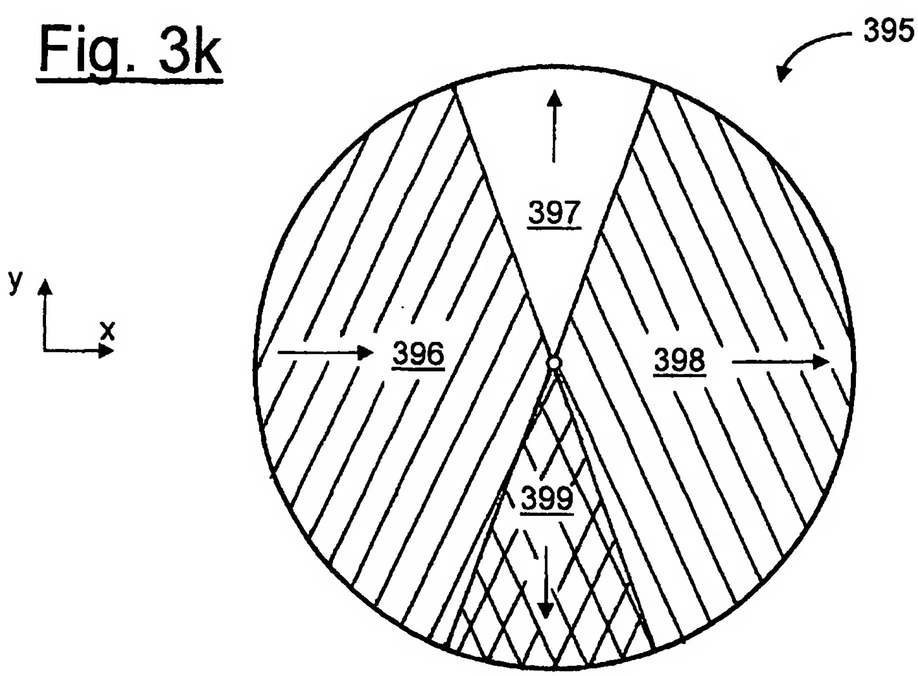


Fig. 4

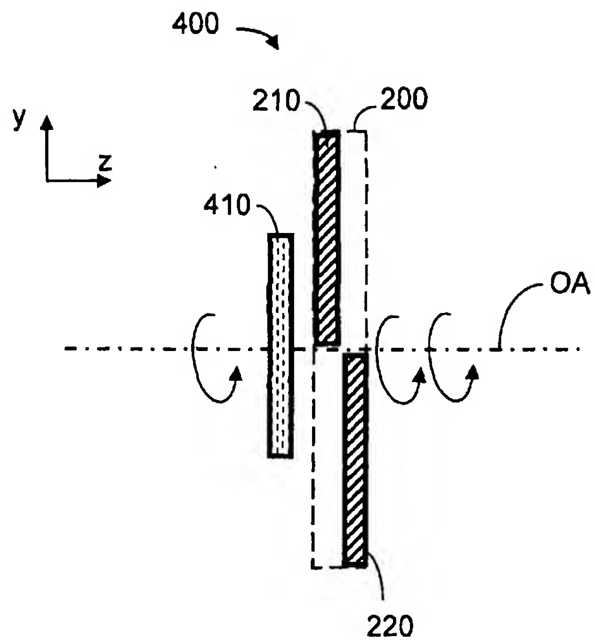


Fig. 5a

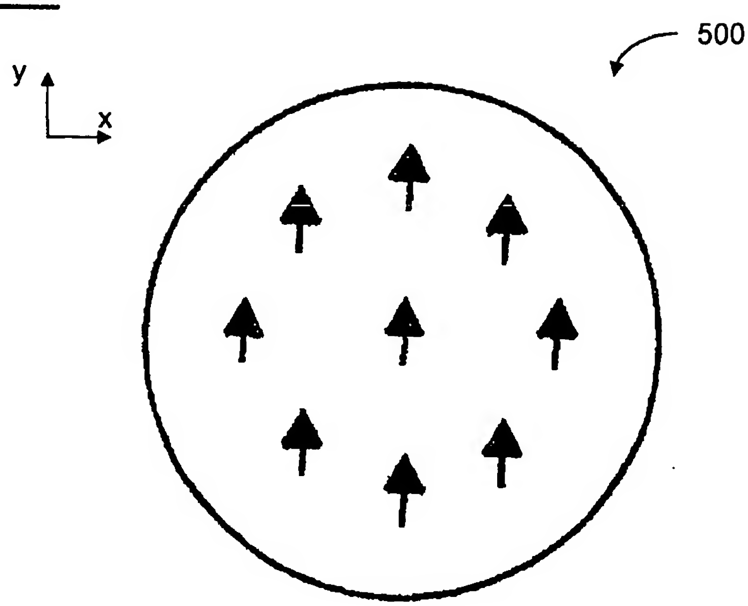


Fig. 5b

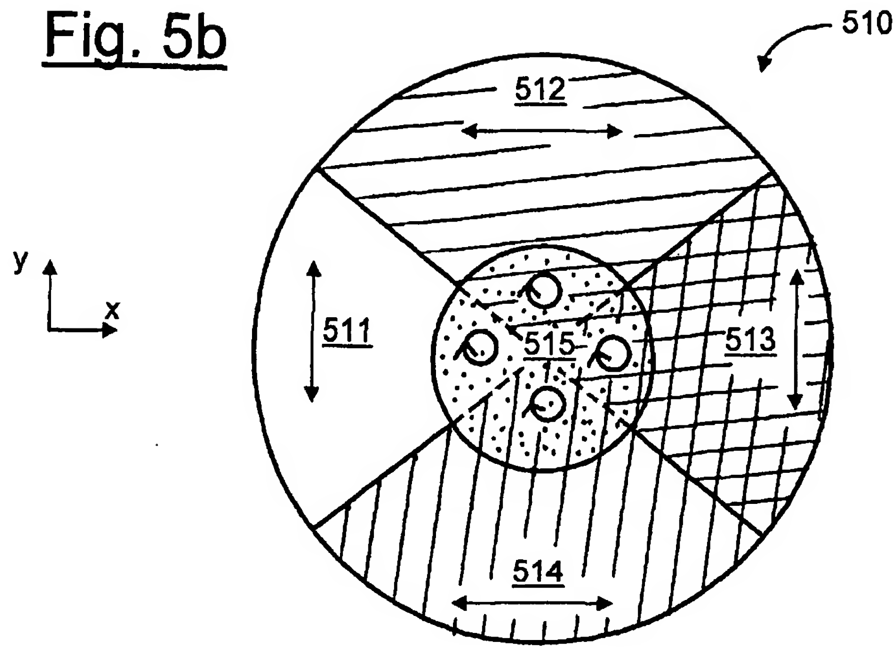


Fig. 5c

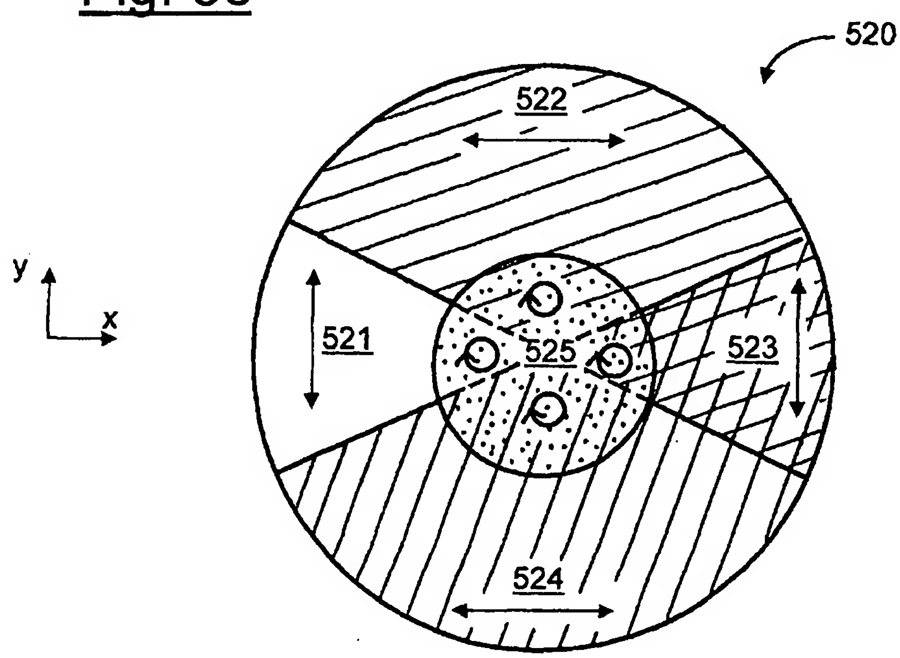


Fig. 5d

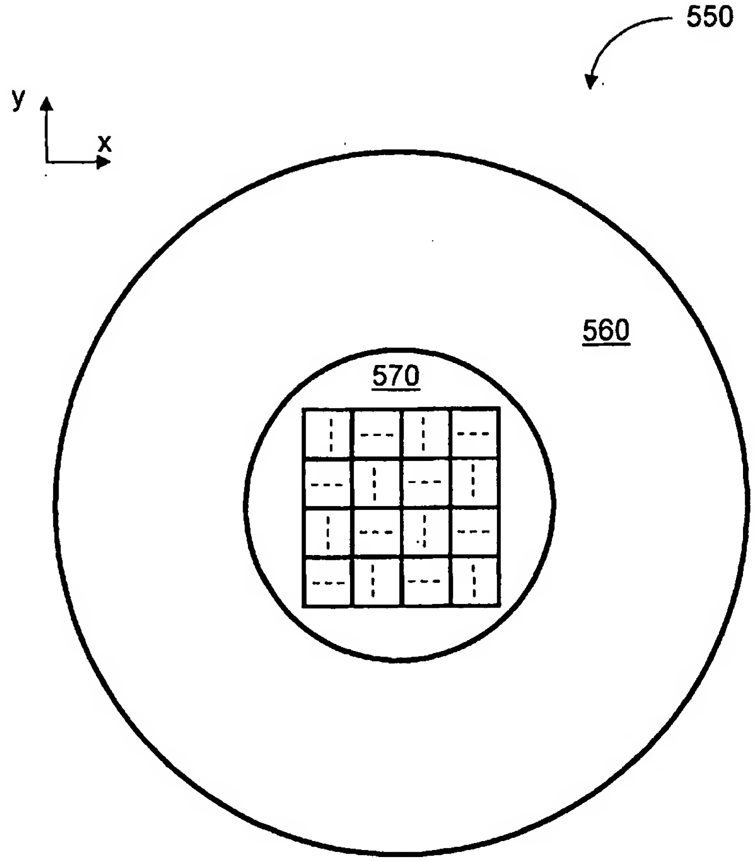
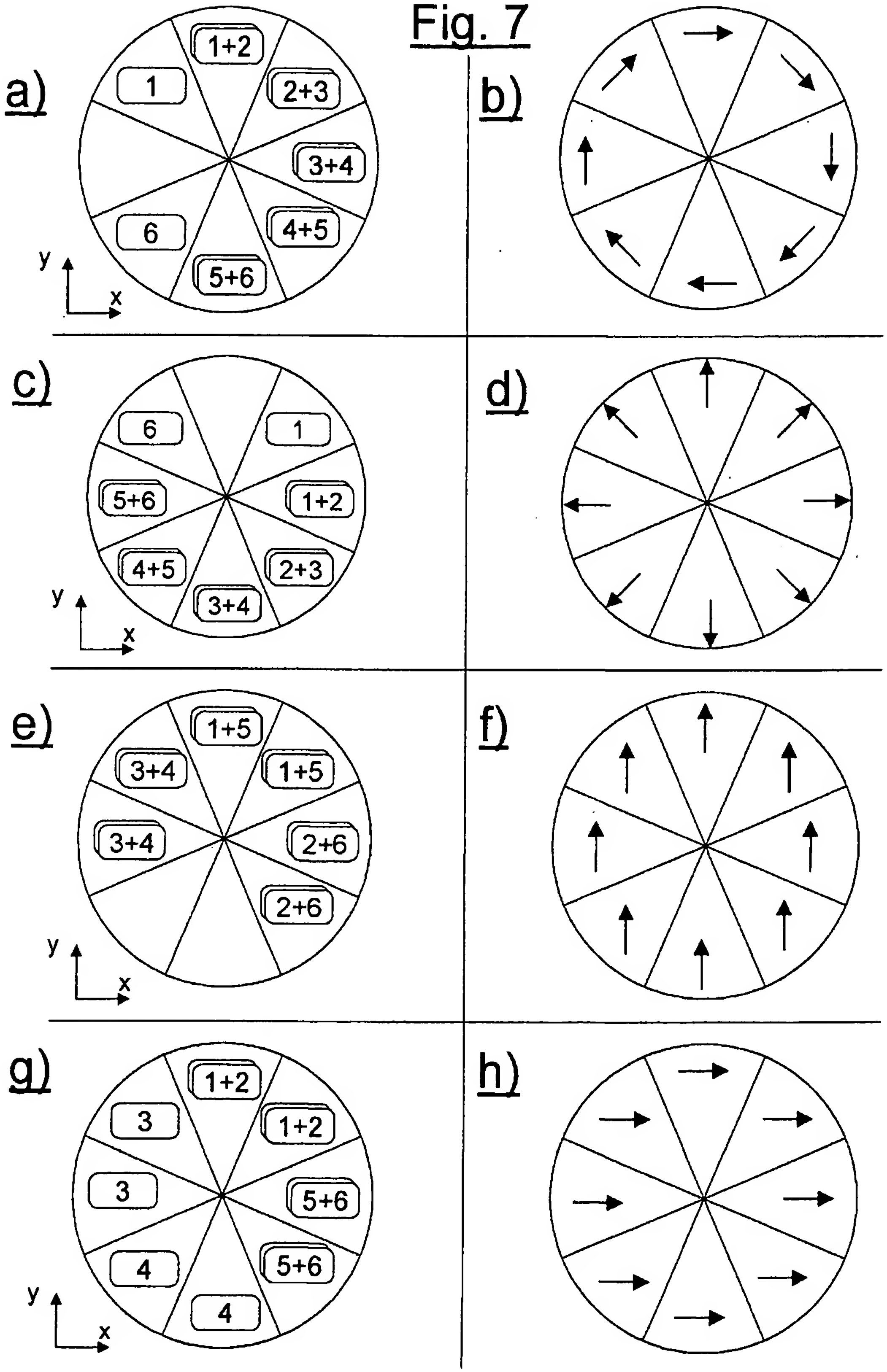


Fig. 6

		1	2	3	4	5	6
	0° ↑	45° ↗	45° ↗	90° →	90° →	135° ↘	135° ↘
1			90° →	135° ↘	135° ↘	180° ↓	180° ↓
2				135° ↘	135° ↘	180° ↓	180° ↓
3					180° ↓	225° ↙	225° ↙
4						225° ↙	225° ↙
5							270° ←
6							

Fig. 7


a)
1
1+2
2+3
3+4
4+5
5+6
6
y
x
b)
c)
6
1
5+6
1+2
4+5
2+3
3+4
y
x
d)
e)
1+5
3+4
1+5
3+4
2+6
2+6
y
x
f)
g)
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3
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3
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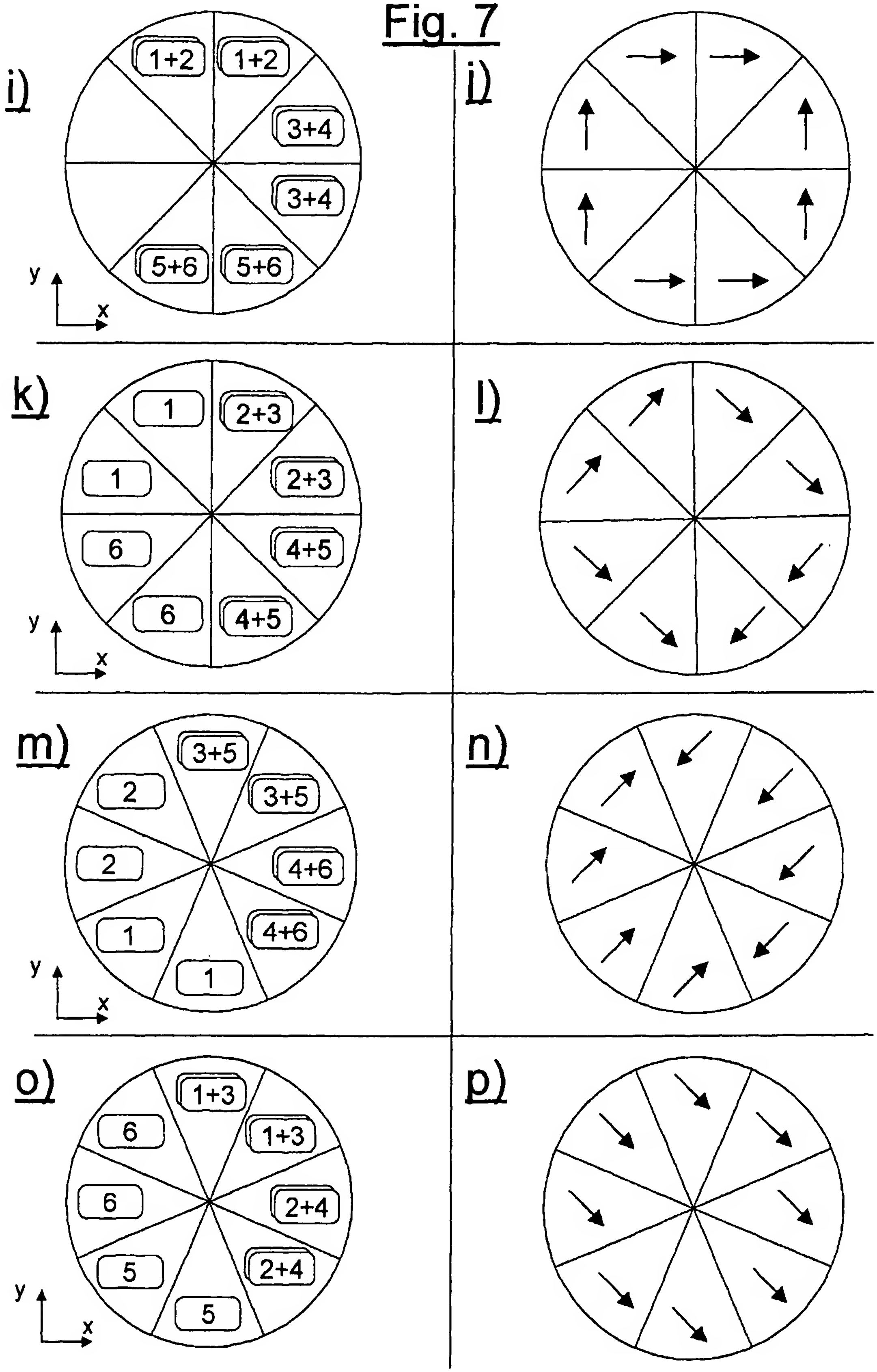
4
5+6
4
y
x
h)

Fig. 7


i)
1+2
1+2
3+4
3+4
5+6
5+6
y
x
j)
k)
1
2+3
1
2+3
6
4+5
6
4+5
y
x
l)
m)
3+5
2
3+5
2
4+6
1
4+6
1
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x
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o)
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5
2+4
5
y
x
p)

Fig. 8

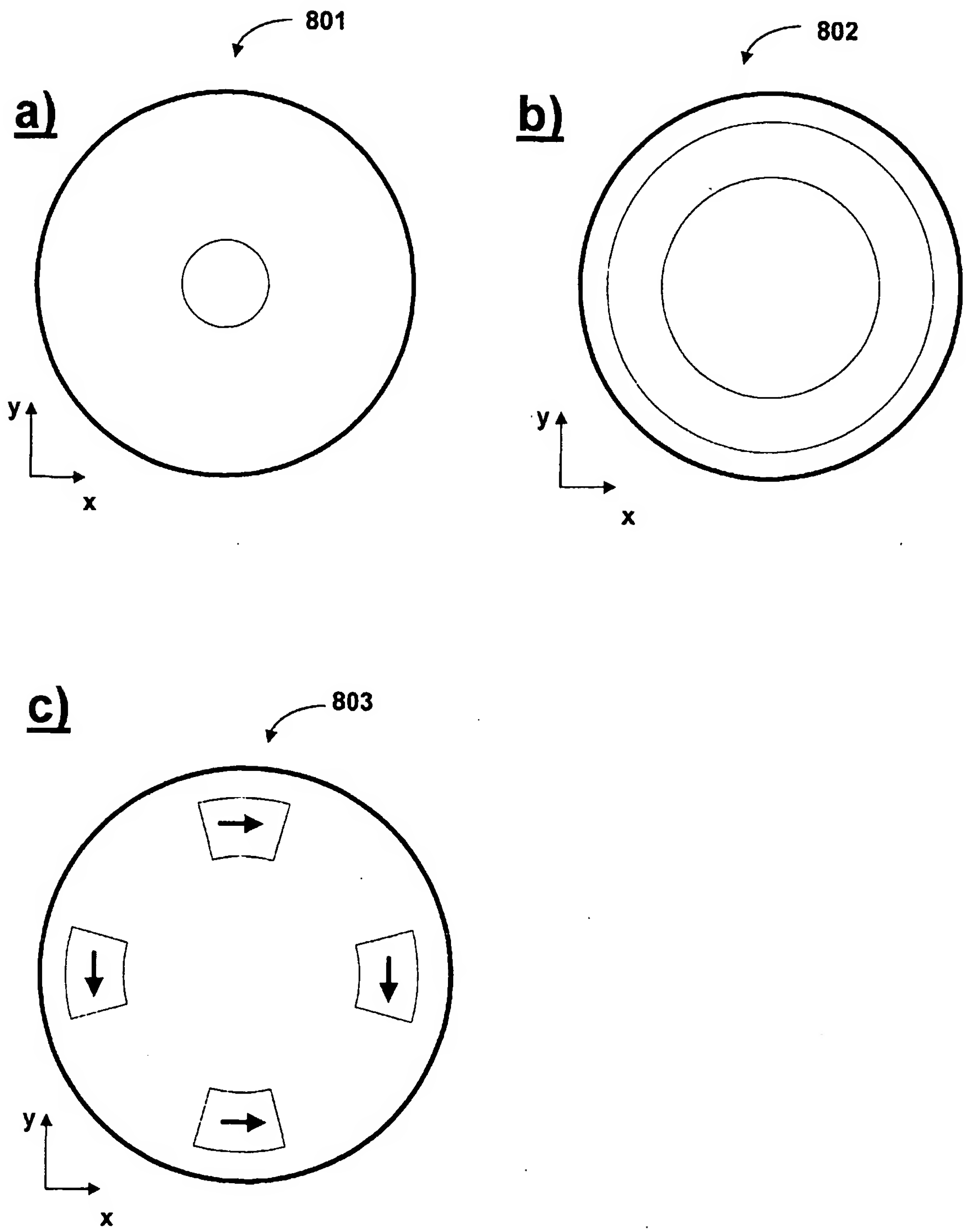
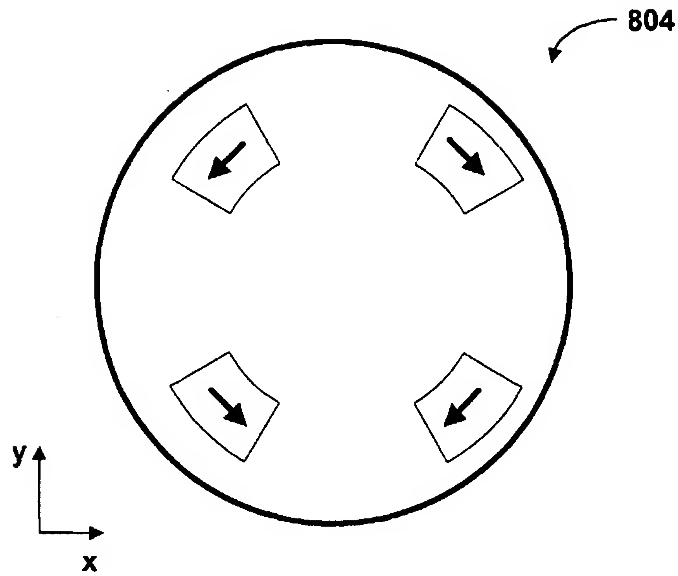


Fig. 8

d)



e)